

Kick-off Meeting

Convened at:

NASA-Glenn Research Center

Glenn Daehn

Presenting for Ohio State Materials Team

Jim Williams-Mat. Sci & Engr.

Mike Mills-Mat Sci & Engr.

Somnath Ghosh-Mech. Engr.

Mark Walter-Mech. Engr.

11/18/02

Improved Performance and Reliability Materials

Tasks:

- * **Materials Support for Performance and Life Methods Modeling**
 - ▲ Properties: typicals and minimums
 - ▲ Materials Characterization
- * **Higher Temperature Capability**
 - ▲ Airfoil Materials
 - ▲ TBCs
 - ▲ Disk Materials (to be added later and/or funded elsewhere)
- * **Low Emission Combustor Materials**

Benefits of Further Improvements

Reliability

- * Longer range twin engine aircraft
 - ▲ ETOPS now standard - extend ETOPS approval
 - ▲ Lower maintenance cost
- * Lower operating cost
- * Improved fleet management (UER $\approx 0.08\%$)

Performance - Lower Fuel Consumption (SFC)

- * Longer range
- * Lower operating cost

Environmental

- * Lower emissions and noise

Higher T's Require Improved Materials

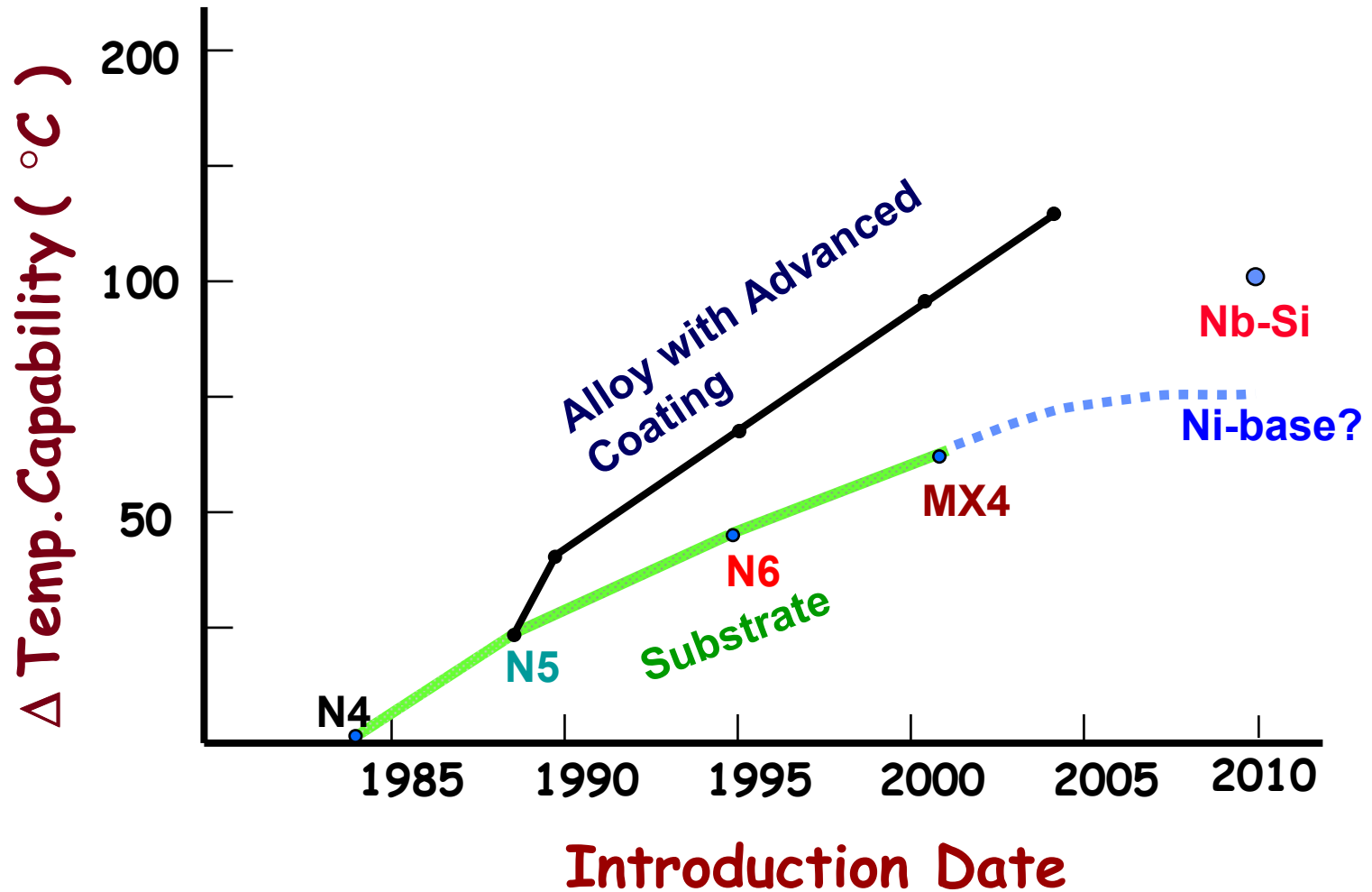
Important “Rules of Thumb”:

- $55\text{ }^{\circ}\text{C } \Delta T_3 \approx 4 - 5\% \text{ SFC}$
- $55\text{ }^{\circ}\text{C } \Delta T_3 \approx 50\text{ }^{\circ}\text{C } \Delta T_{41}$

- * This requires better disk and turbine blade materials
- * Approximate cost of introducing new disk material is \$35M (this is a major decision)
- * Approximate cost of introducing new turbine blade material is \$10M (assumes minor castability changes)
- * If T_3 and T_{41} are high enough:
 - ⌋ improved casing materials
 - ⌋ improved compressor blades (cast Ni-base alloys?)

More fuel efficient engines come at a substantial cost

Airfoil Alloy Trendline



2.2.1.1 High Temperature Materials

2.2.1.1.2 Near-Net Shape Refractory Intermetallic Composites

M. J. Mills, H. L. Fraser and J. C. Williams , MSE / OSU

Science & Technology Objective(s):

- Pursue a revolutionary advance in the fabrication and performance of turbine blades / static compressors
- Utilize the laser engineered net-shaping (LENS™) process to produce Nb-Ti-Si in-situ composites

Collaborations:

- Government - NASA Glenn Research Center
- Industry - GECD (Bernard Belway), Optimec (R. Grylls), Reference Metals (T. Cadero)
- Synergism with existing programs - Center for Accelerated Maturation of Materials (CAMP / OSU)

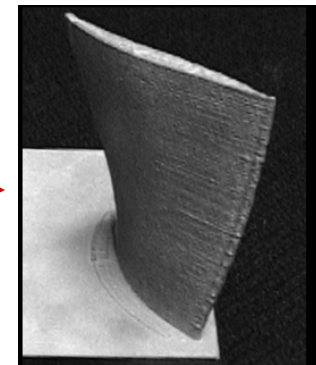
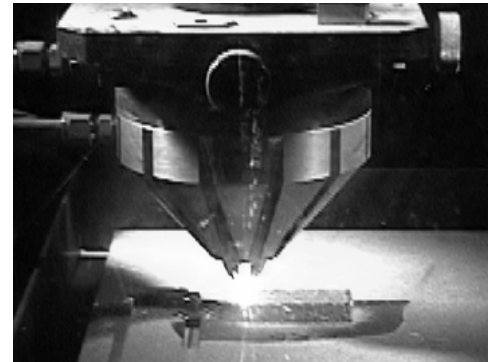
Proposed Approach:

- Using existing LENS™ facility (OSU), produce deposits from elemental powder blends
- Analysis of microstructure/mechanical/oxidation properties
- Optimization of composition/microstructure/properties via combinatorial approaches

NASA Relevance/Impact:

- Cost-effective route to improved high-temperature turbine engine components
- Complex, near-net shaped and functionally graded structures can be processed

LENS™ to Produce Novel Microstructures and Components:

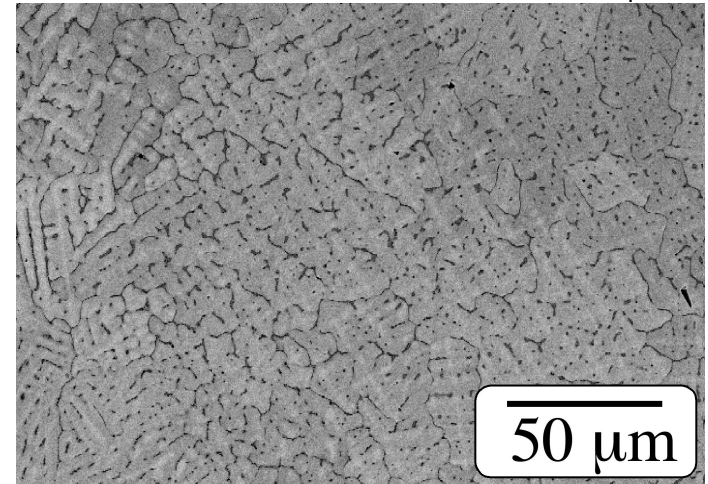
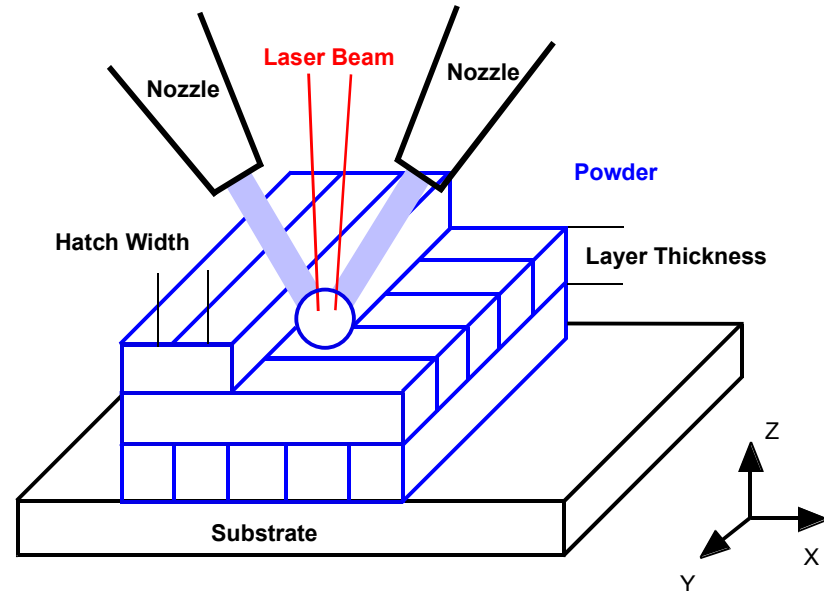


Milestones/Accomplishments:

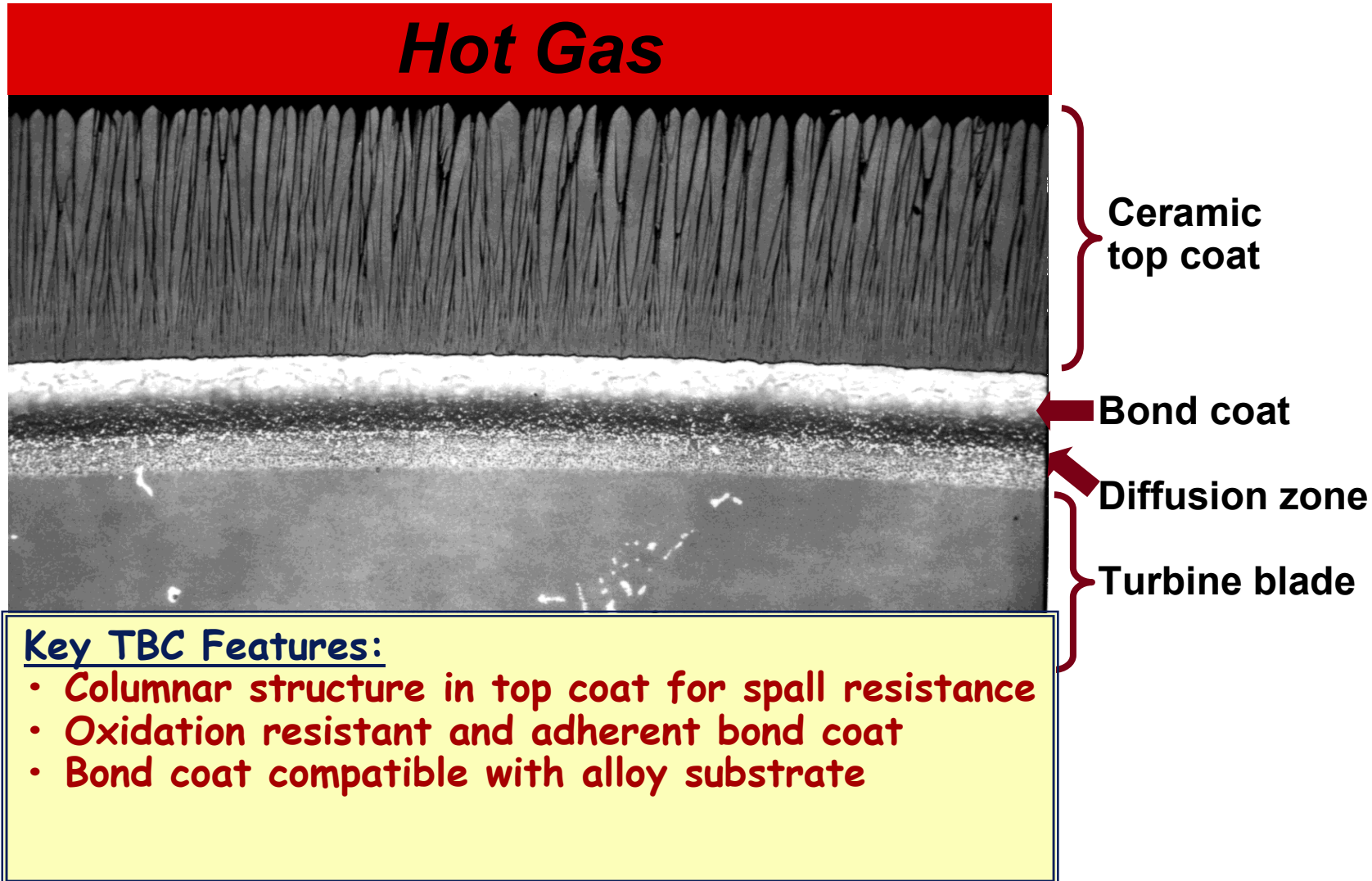
- Obtain suitable Nb powders from reference Metals or other vendors and perform trial depositions
- Produce wide range of compositions in Nb-Ti-Si system for fabrication and detailed analysis
- Microstructure characterization using SEM/TEM/FIB techniques.
- Mechanical testing and oxidation studies as a function of composition.
- Use generated database to target promising compositions with compositionally graded structures for optimized performance.

2.2.1.1.2 Proposed Approach

- Use existing LENSTM facilities in MSE/OSU. In LENSTM, a focused laser light source is used as a heat source to melt a feed of metallic powder to build-up a solid, three-dimensional object
- Advantages include:
 - Complex, near-net shapes can be fabricated
 - Potentially attractive, non-equilibrium microstructures can be created
- Novel approach utilizes *elemental* powder feedstocks since they are:
 - Much cheaper than pre-alloyed powders
 - When phases formed have a negative enthalpy of mixing, can produce fine, dense and homogeneous microstructures
 - Graded compositions can be readily generated
- Already demonstrated to produce desirable microstructures in the Nb-Ti-Si-Cr alloy system



Thermal Barrier Coatings



2.2.1.1 High Temperature Materials

2.2.1.1.1 Thermal Barrier Coatings (TBCs)

M.E. Walter and S. Ghosh, The Ohio State University

Science & Technology Objective(s):

- To develop a comprehensive, systems-based model for thermal and environmental barrier coatings.
- To enable microstructural and materials design for optimized performance and life of TBCs

Collaborations:

- Government – NASA GRC: Environmental Durability Branch
- URETI – integration with turbine blade materials development
- Industry – GE Aircraft Engines
- Synergism with an existing NSF (experimental) program

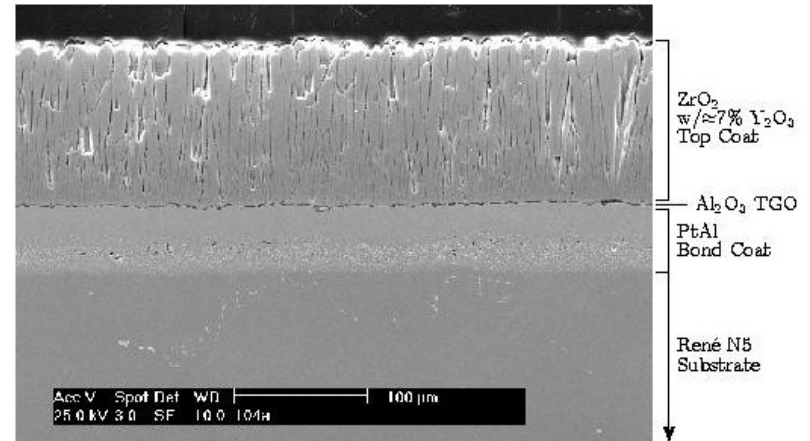
Proposed Approach:

- Start with EB-PVD coatings with PtAl Bond coats and superalloy substrates
- Compare simulations to existing data.
- Simulate top coat materials with varying degrees of compliance CMAS depositions.

NASA Relevance/Impact:

- Improved TBCs are an integral part of higher T_{41}

The Cross-Section of a State-of-the-Art TBC System:

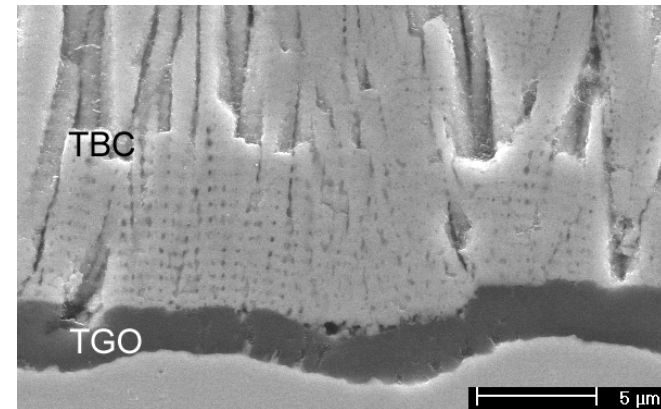
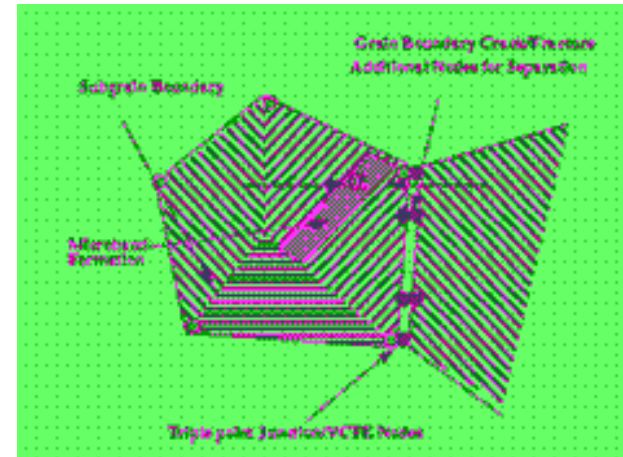


Milestones/Accomplishments:

- Finite element framework oxide growth
Incorporation of wrinkling of the bond coat/TGO/top coat interface
- Include finite elements to enable damage propagation.
- Study top coat sintering and CMAS depositions.
- Compare simulations to experiments.

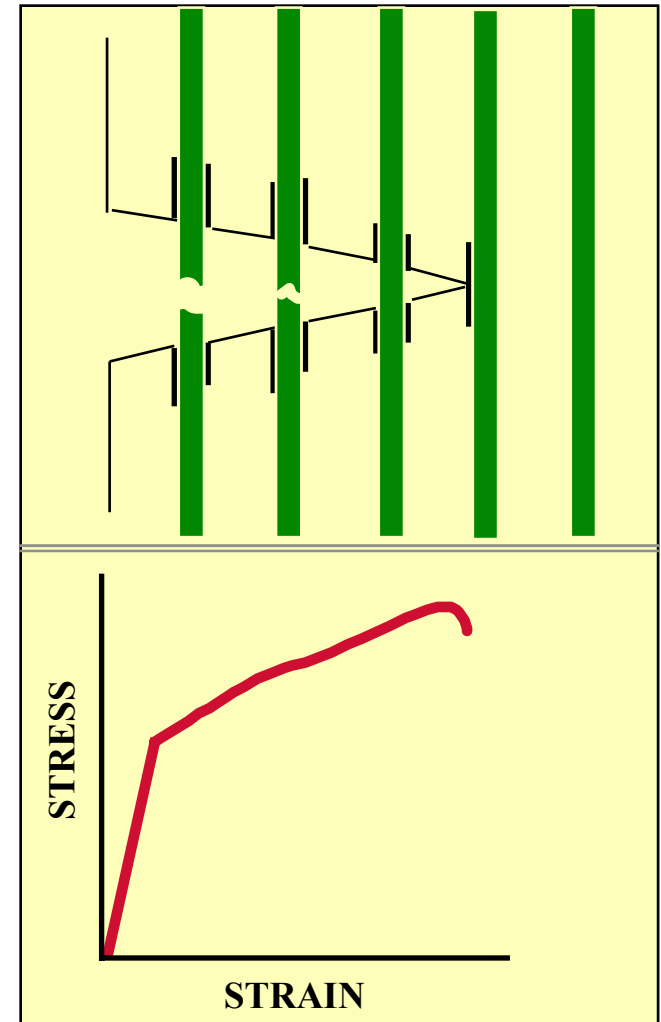
2.2.1.1.1 Proposed Approach

- Begin with models of EB-PVD coatings with PtAl Bond coats and superalloy substrates which incorporate phase evolution, thermally growing oxide, and damage evolution.
- Compare simulations of isothermal and thermocyclic loading to existing experimental data.
- Simulations of top coat materials with varying degrees of compliance and accounting for sintering and CMAS depositions.
- Investigate alternative top coat materials and structures through materials design simulations.
- To design an optimal set of residual stresses and crack compliances for improved coating performance and life.



Desirable CMC Characteristics

- **High Temperature Capability**
 - Environmentally Stable Constituents
- **Thermal Shock Resistance**
 - High Thermal Conductivity
 - High Matrix Strength
- **Damage Tolerance**
 - Continuous Fiber Reinforcement
 - Retention of Fiber Dominated Behavior
- **Affordable**
 - Multiple sources
 - Common fiber type?
- **Good Shape Forming Capability**
- **Environmental Durability**



No affordable production sources today

Demonstrator CMC Combustor Inner Liner



- Successfully Completed Rig Testing With SiC/SiC CMC Inner Liner
- Post-Test NDE Showed No Signs of Material Degradation
- Rig Test Conditions;
 - 15 Hours at F110 Conditions
 - 40+ Hours at IHPTET Conditions
- Next Step-ATEGG Core Engine Test Initiated

2.2.1.1 High Temperature Materials

2.2.1.1.3 Co-Continuous Composites

Glenn Daehn, & Jim Williams, The Ohio State University

Science & Technology Objective(s):

- Develop new class of high temperature ceramic-metal composites. Will possess: low density, good toughness, high temperature strength, low processing cost.

Collaborations:

- NASA- Glenn (background/constraints re/CMC's)
- GEAE (background/constraints re/CMC's)
- BFD, Inc. (Processing technology)

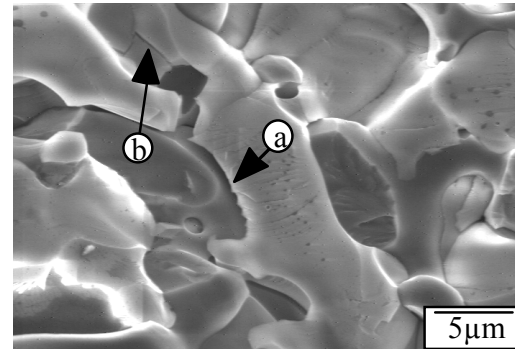
Proposed Approach:

- Visit CMC experts at NASA-Glenn, GEAE and WPAFB - detail project design and ensure relevance.
- Design new desired microstructure involving continuous ceramic and metal phases
- Produce materials and measure properties

NASA Relevance/Impact:

- Conventional superalloys are reaching fundamental performance limits. New materials proposed that can provide higher operating temp., low density, without poor toughness and high cost of similar materials.

Example- Fracture Surface, Ni Al - Al_2O_3 co-continuous composite:



Lighter phase is NiAl. Composite tougher than constituents. De-bonding (a) and deflection (b) shown here.

Milestones/Accomplishments:

- CMC state of the art report and detailed project objectives (after consultation with collaborators)
- Microstructural objectives and processing plan for new materials.
- Demonstrate production of new materials.
- Measure and report properties.

2.2.1.1.3 Proposed Approach - Reactive Infiltration

Established Processing Scheme

SiO₂ shaped precursor is immersed in liquid Al at 1100° C.

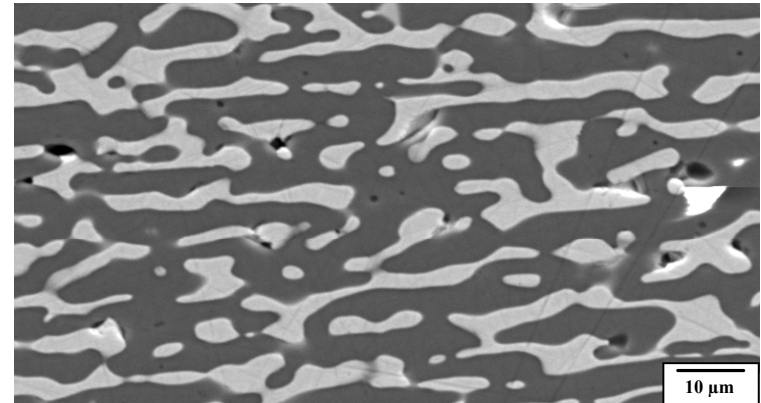


As 2 moles of Al₂O₃ are smaller than 3 moles of SiO₂, porous alumina is created and infiltrated!

Process is net-shape.

Enhancements in this program

- Use high melting metal or intermetallic to fill pores in ceramic instead of aluminum.
- Add continuous ceramic fibers as well.



Example, NiAl Al₂O₃ composite. Dark phase is ceramic.

Summary and Take-aways

- * Substantial progress in aero engine performance in past 25 years
 - ▲ Materials have played a major role in this
- * Further improvements will require major materials investment in Ni-base disks and blades
 - ▲ Continued improvements in Ni-base turbine blades open to question
- * Lower emissions combustors require better liner materials
 - ▲ CMCs are the best bet
- * Opportunities in other lighter weight and higher temperature materials await market pull and industrial base investment
 - ▲ Should do enabling work now

Summary of Progress - past 25 years

- * **Thrust:weight has increased ~2.5X**
 - ▲ Higher operating temperatures
 - ▲ Lighter weight structures and materials
- * **Time on wing has increased ~40X**
 - ▲ Reduced inspections
 - ▲ Improved combustor pattern factors
 - ▲ Improved hot section materials
- * **Fewer delays, cancellations, unscheduled removals and in-flight shut downs**
 - ▲ Broad use of FADEC
 - ▲ Better bearings
 - ▲ Improved controls and accessories
 - ▲ More EGT margin
 - ▲ ETOPS now routine

Disk Task to be funded elsewhere

Funding Possibilities:

- *FAA & additional funding
- *Ohio/NASA/USAF Propulsion 21
- *GE company funded program

Advanced Disk Alloy Goals

- Density < Predecessor (.297 vs. .302)
 - Tensile (UTS) \cong same
 - Creep/Rupture (+30°C improvement)
- } Lighter Weight
- LCF \cong same until 650°C; Superior >650°C
 - SPLCF > same
- } Enables Higher T3
- Cyclic FCGR \cong same
 - Dwell FCGR 50X slower (+80°C Capability)
- } Superior Probabalistic Life

Improved stability alloy enables high temperatures & long hold times use while maintaining lower temperature properties

Advanced Disk Alloy Capability

